IS THE HEAT GENERATED BY GREAT CITIES CHANGING THEIR CLIMATES?

By ANDREW H. PALMER, Blue Hill Observatory.

The statement has frequently been made that the heat generated by great cities is changing their climates, causing them to grow warmer and drier. It is maintained that heat from many and varied sources is raising the average temperature of the air for a distance of a mile or more above the large cities. It is further alleged that zero temperatures, which were once common during winter in certain cities are now infrequent; that the rainfall has decreased at a particularly rapid rate during recent years; that the snowfall is getting less and less each winter; and that the number of cloudless days has increased from year to year; all of which are readily explained by the reported discovery of increasing city temperatures. One of the champions of these views is reported to have said: "If these conclusions are well based, then we must look forward to an increasing degree of artificial interference with the course of nature as the population and its fuel consumption grow." Half a century ago Mr. Luke Howard observed that "the temperature of the city (London) is not to be considered that of the climate; it partakes too much of an artificial warmth, induced by its structure, by a crowded population, and the consumption of great quantities of fuel in fires." (Quarterly Journal of the Meteorological Society, Vol. III, 1877, p. 313.) Mr. H. S. Eaton, while president of the Meteorological Society, asked in an address delivered before that society February 21, 1877, "Who can doubt that the climate of London has been modified by the growth of its population and of the consumption of fuel?" He calculated that the artificial and animal heat liberated within the city was sufficient to raise the mean temperature of a stratum of air 100 feet thick over the 118 square miles of metropolitan London 2.5° every hour.

Startling statements of this kind naturally invite a test of their truth. Such a test is attempted in the following study of the climatic characteristics of Boston, Mass. The data forming the basis for the study are taken from the official records of the United States Weather Bureau and of Blue Hill Observatory. Records of the Signal Service and of the Weather Bureau cover the period from 1871 to 1910, inclusive, while records of the Blue Hill Observatory cover the last quarter century. If there has been any change in the climatic characteristics of Boston within recent years it should be evident from a comparison of the records of the two institutions. While Boston has changed greatly within the 40 years for which data are available, the immediate environment of Blue Hill Observatory has remained practically unchanged since its foundation by Prof. A. Lawrence Rotch in 1885. During the period considered the exposure of the instruments at the Boston office of the Weather Bureau was changed twice, but as the displacement in each case was a matter of a few feet only, no correction was made by the bureau. The instruments are at present located upon the roof of the post-office building, 115 feet above the street level, or 125 feet above mean sea level. At the Blue Hill Observatory the instruments are kept outside in an inclosure about 50 feet from the building, their height being 635 feet above sea level. The same kinds of standard instruments are employed at the two stations, the thermometer in each case being kept in a Hazen shelter, and the cylindrical rain gauge resting upon the roof in Boston and upon the ground at Blue Hill.

TEMPERATURE.

In Table I are given the mean annual temperatures at Boston and at Blue Hill for 40 years, the data for Blue Hill previous to 1886 having been interpolated from a record kept at Milton Center (3½ miles northeast of and 580 feet lower than the observatory), and corrected to make them continuous with those since obtained at the observatory. From the fact that the differences between the mean annual temperatures of Boston and Blue Hill are not increasing from year to year it is not apparent that the increased amount of heat evolved at the former place is having any appreciable effect upon its temperatures. Moreover, the general trend of the temperatures of Boston is about stationary, there being no persistent change upward or downward. Like all other climatic data, the mean temperature varies from year to year, but a smoothed curve representing them all would be practically a straight line. A comparison shows that all of the mean annual temperatures of Boston are somewhat higher than those for Blue Hill. Similar differences are found whenever urban and suburban temperatures are compared, and are usually explained by such differences between the two places as (*a*) the greater heat retaining power of buildings, street pavements, etc, in cities as contrasted with open fields; (*b*) the relatively stagnant condition of the air in cities owing to the sheltering effects of structures as compared with the ease with which air is mixed by the wind in the outlying districts; and (*c*) a lesser radiation of heat at night in cities because of the presence of smoke. After discovering that the minimum temperatures recorded during the cold waves of January, 1884, in the larger cities of Ohio were from 2° to 8° higher than those recorded in the outlying districts, Prof. T. C. Mendenhall concluded that the discrepancies were explained largely by differences in exposure between the two groups of stations. (Science, III, 1884, p. 306.) So largely are temperatures affected by the environment of the thermometer that he urged that stations be placed near, rather than in, large cities, sufficiently distant to remove them from local effects, a policy now being pursued to some extent by the Weather Bureau. This persistent difference between urban and suburban temperatures should not be confused with the alleged progressive increase in city temperatures. It should also be stated at this point that the "sensible temperature" in the city is higher than that in the country because of the greater radiation and reflection of heat from walls and streets in the former place.

Comparisons of this kind are important in deciding the question at issue, for when the Boston temperatures alone are studied it is hard to reach a conclusion, as the data are irregular and sometimes conflicting. Two years have had mean temperatures at least 2° below the

normal for the period, these years being 1875 and 1904, while in but one year was the mean 2° or more above the normal, that year being 1908. In regard to the seasons, the winters of 1880, 1890, and 1906 had positive departures of 4° or more from the mean winter temperature for the period, while the winters of 1873, 1875, 1904, and 1905 had negative departures of the same amount. (By the winter of any year is meant the winter during which the year began—the winter of 1880, for example, means the winter of December, 1879, to February, 1880.) The springs of 1871, 1894, 1902, 1903, and 1910 had positive departures of 3° or more, while those of 1874, 1882, 1885, and 1888 had equally large negative departures. The summers of 1872, 1876, 1900, and 1908 were 2° or more warmer than the mean, while those of 1886, 1902, and 1903 were that much colder than the average. In 1881, 1900, and 1908 the autumns were at least 3° higher than the average, while in 1871, 1873, 1875, and 1876 they were that much colder than the mean. Ten of the 15 relatively warm seasons occurred during the second half of the period, while 11 of the 15 relatively cold seasons occurred during the first half.

In Table II are given the warm and cold months during the last 40 years, a month having been termed warm or cold when its departure equalled or exceeded the amount stated. These amounts are wholly arbitrary. By actual count 16 relatively warm months occurred in the 20 years 1871 to 1890, inclusive, while 23 occurred during the 20 years 1891 to 1910, inclusive. Moreover, 26 relatively cold months occurred during the first of these two periods, while but 12 occurred during the second.

The number of days (*a*) with a maximum temperature of 32° or below, (*b*) with a minimum temperature of 32° or below, and (*c*) with a minimum temperature of 0° or below for each of the winters from 1872 to 1909 is given in Table III. An inspection of the table will show that although the number of days in each case varies from year to year, no persistent increase or decrease is apparent, unless it be the fact that during the first half of the period in only one winter there were no days with a minimum temperature of 0° or below, while during the latter half there were six such years. During the 18 winters preceding that of 1890-91, 518 days had maxima of 32° or below, while during the 18 years following it there were 572 such days. Of days having minimum temperatures of 32° or below, 2,065 occurred during the first of these periods, while 1,878 occurred in the second. Again 66 days in the earlier period had minimum temperatures of 0° or lower, while there were but 39 such days during the later period. As far as maximum temperatures are concerned, it was found that during the period 1872 to 1908, inclusive, there were 261 days on which the temperature reached 90°. Of these 134 occurred before 1890, while 122 occurred since that year.

Observations made at Baltimore, Md., during a period of 88 years, 1817 to 1904, inclusive, do not lend support to the contention stated at the beginning. (O. L. Fassig, The Climate and Weather of Baltimore, p. 93.) During the first half of this period the mean temperature in each of two years was at least 2° lower than the normal, while during the latter half the number was four. On the other hand six of the first 44 years were at least 2° warmer than the normal, while but two of the last 44 years were similarly warm. The latter fact is exactly contrary to what one should expect if the contention stated above were true. It is interesting to note that whereas the mean temperature for the whole period is 55.6°, the mean for the period 1817 to 1870, inclusive, is 55.9°, while that from the period 1871 to 1903, inclusive, is but 55.3°.

Data obtained from the archives of the Observatory of Paris, covering a period of 71 years, 1800 to 1870, inclusive, fail to show any heating effect caused by the increasing amount of heat evolved by that city. The average temperature for the 35 years preceding and succeeding the year 1835 is exactly the same, 51.3° Three negative departures in the mean annual temperature amounting to at least 2° occurred in each half of the period, whereas all the positive departures of that amount, three in number, occurred during the first 35 years.

PRECIPITATION.

In Table IV are contained the annual precipitation for Boston during the last 40 years and that for Blue Hill the last 25 years. While the preciptation varies greatly from year to year at each of the two places, there is no apparent increase in the difference between the two such as would be the case if, as one expressed it, the "ascending mass of hot gases from the city prevent rain fall within the city by warming the upper layers of air and increasing their capacity to absorb water."

An examination of the table will show that the annual precipitation in Boston is less than that at Blue Hill. In this connection it should be remembered that the rain gauge on Blue Hill is 510 feet higher than that in Boston, and that the high buildings in the vicinity of the Boston post office deflect winds from certain directions to a considerable degree, and thus necessarily affect the rainfall to some extent. However, the point to be emphasized here is the fact that the difference between the annual precipitation recorded in Boston and on Blue Hill is not increasing appreciably.

The mean annual precipitation in Boston for the 20 years, 1871 to 1890, inclusive, was 45.91 inches, while that for the 20 years, 1891 to 1910, inclusive, was 38.80 inches. At first sight a decrease of over 7 inches per year in the average seems to lend support to the statement quoted above, but as a matter of fact the rainfall has been deficient in recent years all over New England, whether the observations were obtained in cities or in the country. This is true also in regard to snowfall, for measurements made at the base of Blue Hill show that the average snowfall there during 5 of the last 6 years was below the normal for the last 25 years. Moreover, city dwellers frequently forget that snow is carted away from city streets and that it melts more rapidly upon brick pavements and the roofs of houses than upon bare and frozen fields. Persons moving from rural or suburban homes to steam-heated apartments in the city naturally conclude that the winters there are milder and are accompanied by less snowfall. Moreover, the man who recalls the deep snows of his boyhood often fails to realize that it was much more difficult for him to wade through 2 feet of snow when he was 4 feet tall than when his height had become 6 feet.

Records of precipitation for Baltimore, Md., covering the 87 years, 1817 to 1903, inclusive, show no decrease in the annual rainfall parallel to the growth of the city. The average annual precipitation in inches for each of the 8 decades beginning with that of 1821–1830 is as follows: (1) 38.01, (2) 41.25, (3) 37.82. (4) 41.46, (5), 32.10, (6) 41.36, (7) 47.22, and (8) 40.49. The mean annual precipitation for the period 1817 to 1870, inclusive, is 38.13 inches, and that for the period 1871 to 1903, inclusive, is 43.34 inches.

SUMMARY AND CONCLUSIONS.

In the data given above there is little that suggests a positive answer to the question which forms the subject of this discussion. If local causes produce an increase in the temperature of the air in a city, it ought to be shown by a constantly increasing difference between the temperatures recorded in that city and those obtained outside in the country, a fact not apparent in the comparison of the data for Boston and Blue Hill. Moreover, if the temperature within a city is rising it would be shown by an increase in the mean annual temperatures, a condition not found in the long series of temperature observations for Boston, Baltimore, and Paris. The fact that city temperatures are usually higher than those recorded outside in the country districts is probably explained by the differences in the controls referred to in the preceding discussion, and can hardly be due to the effects of heat evolved by the city, as the greatly diminished amount of heat thus lost in summer has no apparent effect upon the differences in temperature. In regard to the frequencies of certain fixed temperatures the data are more or less conflicting. Precipitation, when Boston and Blue Hill are compared, shows little to support the idea of changing climate in the city. The conclusion must therefore be that judging from the evidence available the heat generated by great cities is not changing their climates in any appreciable degree.

TABLE I.—*The mean annual temperatures of Boston and Blue Hill compared.*

Year	1871	1872	1873	1874	1875	1876	1877	1878	1879	1880
Boston	48.9	48.8	48.2	48.6	46.6	47.9	50.1	50.2	48.4	50.3
Blue Hill	45.0	44.2	44.0	44.7	42.9	45.5	47.1	47.0	45.6	47.1
Difference	3.9	4.6	4.2	3.9	3.7	2.4	3.0	3.2	2.8	3.2
Year	1881	1882	1883	1884	1885	1886	1887	1888	1889	1890
Boston	49.6	48.8	47.9	49.0	47.6	48.4	48.5	47.3	50.7	49.1
Blue Hill	45.8	45.2	44.2	46.3	45.1	46.2	46.1	44.4	47.7	46.3
Difference	3.8	3.6	3.7	2.7	2.5	2.2	2.4	2.9	3.0	2.8
Year	1891	1892	1893	1894	1895	1896	1897	1898	1899	1900
Boston	50.4	49.4	47.9	50.3	49.8	49.2	49.9	50.8	50.2	50.8
Blue Hill	47.9	46.7	45.6	48.0	47.2	46.8	47.3	48.2	47.5	48.6
Difference	2.5	2.7	2.3	2.3	2.6	2.4	2.6	2.6	2.7	2.2
Year	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910
Boston	49.0	49.6	49.5	47.1	49.1	50.0	48.7	51.2	50.6	50.8
Blue Hill	46.7	47.5	47.3	44.7	46.5	47.7	45.6	48.7	47.5	48.0
Difference	2.3	2.1	2.2	2.4	2.6	2.3	3.1	2.5	3.1	2.8

TABLE II.—*Relatively warm and relatively cold months in Boston.*

WARM MONTHS.

Month.	Departure.	Year.
January	6° or more	1880, 1889, 1906.
February	6° or more	1877.
March	6° or more	1871, 1894, 1898, 1902, 1903, 1910.
April	5° or more	1910.
May	4° or more	1880.
June	4° or more	1883, 1892, 1899, 1908.
July	3° or more	1872, 1887, 1910.
August	3° or more	1872, 1898.
September	4° or more	1881, 1884, 1891.
October	4° or more	1879, 1900.
November	4° or more	1889, 1895, 1896, 1900, 1902, 1905.
December	5° or more	1877, 1881, 1889, 1891, 1895, 1899, 1907.

COLD MONTHS.

Month.	Departure.	Year.
January	6° or more	1875, 1888, 1893.
February	6° or more	1875, 1885, 1907.
March	6° or more	1872, 1885.
April	5° or more	1874.
May	4° or more	1882, 1885, 1888, 1907.
June	4° or more	1881, 1897, 1903.
July	3° or more	1884, 1888, 1889, 1891, 1895, 1902.
August	3° or more	1889, 1903.
September	4° or more	1871.
October	4° or more	1876, 1883, 1888, 1889.
November	4° or more	1871, 1873, 1875, 1901.
December	5° or more	1872, 1876, 1880, 1890, 1904.

TABLE III.—*The frequency of certain temperatures in Boston.*

Year.	Maximum, 32° or below.	Minimum, 32° or below.	Minimum, 0° or below.	Year.	Maximum, 32° or below.	Minimum, 32° or below.	Minimum, 0° or below.
1872–73	42	119	5	1891–92	27	94	0
1873–74	29	115	2	1892–93	38	120	2
1874–75	40	128	9	1893–94	35	96	5
1875–76	30	132	6	1894–95	36	120	2
1876–77	34	121	2	1895–96	40	110	4
1877–78	15	89	1	1896–97	31	100	0
1878–79	33	129	1	1897–98	19	90	0
1879–80	17	125	4	1898–99	34	98	6
1880–81	25	124	5	1899–1900	26	102	1
1881–82	17	114	3	1900–1901	34	103	2
1882–83	21	130	1	1901–2	36	96	0
1883–84	31	117	2	1902–3	25	80	4
1884–85	36	115	6	1903–4	41	132	6
1885–86	32	105	8	1904–5	48	128	0
1886–87	32	124	1	1905–6	21	98	1
1887–88	40	113	9	1906–7	40	110	4
1888–89	22	79	1	1907–8	22	100	2
1889–90	22	86	0	1908–9	19	101	0
1890–91	35	108	1				

TABLE IV.—*The annual precipitation at Boston and at Blue Hill compared.*

Year	1871	1872	1873	1874	1875	1876	1877	1878
Boston	45.06	50.23	54.53	43.52	50.15	48.96	51.49	65.53
Blue Hill	.....	.....	.....	.....	.....	.....	.....	.....
Difference	.....	.....	.....	.....	.....	.....	.....	.....
Year	1879	1880	1881	1882	1883	1884	1885	1886
Boston	44.57	37.30	52.63	43.82	35.48	48.98	45.10	42.14
Blue Hill	.....	.....	.....	.....	.....	.....	.....	46.99
Difference	.....	.....	.....	.....	.....	.....	.....	4.85
Year	1887	1888	1889	1890	1891	1892	1893	1894
Boston	33.75	45.89	39.82	39.14	39.70	37.02	41.84	36.62
Blue Hill	43.72	55.84	54.60	50.79	50.27	39.73	45.08	38.24
Difference	9.97	9.95	14.78	11.65	10.57	2.71	3.24	1.62
Year	1895	1896	1897	1898	1899	1900	1901	1902
Boston	40.17	37.55	40.77	49.86	34.69	44.05	48.72	33.93
Blue Hill	46.19	47.44	45.40	58.69	40.67	48.14	54.01	42.71
Difference	6.02	9.89	4.63	8.83	5.98	4.09	5.29	8.78
Year	1903	1904	1905	1906	1907	1908	1909	1910
Boston	41.97	39.64	32.08	40.69	37.56	30.07	40.67	28.33
Blue Hill	46.76	46.19	39.45	45.53	47.57	37.58	43.29	34.27
Difference	4.79	6.55	7.37	4.84	10.01	7.51	2.62	5.94